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extent which would appreciably affect the results. With the polarimetric apparatus at present at our disposal it will be possible to work with considerably smaller salt concentrations and to reduce the concentration of the reference substance as low as 0.01 molal in the case of lithium chloride solutions. By substituting trehalose for raffinose it will probably even be possible to use a considerably lower concentration than this and thus to remove all doubt as to the validity of the assumption in question. Work along these lines will be continued in this laboratory.

A more complete description of the research described in this paper will soon appear in the *Journal of the American Chemical Society*. A detailed description of it has already been printed as part of a doctor's thesis submitted by Earl B. Millard to the Graduate School of the University of Illinois.

<sup>1</sup> Washburn, *J. Amer. Chem. Soc.*, **31**, 322 (1909).

<sup>2</sup> Buckböck, *Zs. physik. Chem.*, **55**, 563 (1906).

## THE ORIGIN OF CORAL REEFS

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*A Journey across the Pacific.* A liberal grant from the Shaler Memorial Fund of Harvard University, supplemented by a subsidy from the British Association for the Advancement of Science, whose meeting in Australia during August I was invited to attend as a foreign guest, enabled me to spend the greater part of the year 1914 in visiting a number of islands in the Pacific Ocean with the object of testing the various theories that have been invented to account for coral reefs. Thirty-five islands, namely, Oahu in Hawaii, eighteen of the Fiji group, New Caledonia of which the entire coast line was traced, the three Loyalty islands, five of the New Hebrides, Rarotonga in the Cook group, and six of the Society islands, as well as a long stretch of the Queensland coast inside of the Great Barrier reef of northeastern Australia, were examined in greater or less detail. Darwin's theory of subsidence is, in my opinion, the only theory competent to account for the coral reefs there seen; thus my work leads to the same conclusion as that reached by several other recent students of this old problem. A full discussion of my observations will be published later, probably in the *Bulletin of the Museum of Comparative Zoology* at Harvard College. A brief statement of the chief results gained here follows.

*Theories of Coral Reefs.* Before setting out on the voyage I reviewed the various theories of coral reefs in an essay that was published during my absence under the title of "The Home Study of Coral Reefs" in the *Bulletin of the American Geographical Society* for 1914. Every one of the several theories is successful in explaining the visible features of the reefs themselves, provided the postulated conditions and the invisible processes of the past are accepted. Evidently then a study of the reefs alone will not suffice to discover which theory really provides a correct mental counterpart of their past and unobservable history. Hence appeal must be made from the non-committal reefs to competent witnesses of some other kind, which were present while the reefs were forming and which are willing to testify about the events which then took place.

*Evidence derived from Barrier Reefs.* In searching for such witnesses it should be borne in mind, first, that as far as fringing reefs A, A, A,

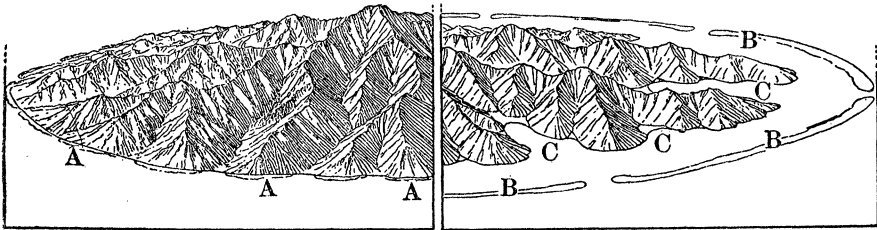


figure 1, are concerned, their origin is hardly in debate; they are growing colonies of corals, initiated by the arrival from elsewhere of passively floating larvae, which establish themselves in shallow water close to a newly offered and suitable shoreline; second, that as far as atolls—or reef-rings enclosing shallow lagoons without central islands—are concerned, they are, unless penetrated by numerous and expensive borings, inscrutable, for they stand alone and bury their past; third, that as far as elevated reefs are concerned, their inner structure and their relation to the foundation on which they were formed would give important evidence regarding their origin, and should therefore be investigated; and fourth, that it is in connection with barrier reefs, B, B, B, figure 1, that the desired witnesses to the facts of the past can be most readily found; for the central volcanic island, rising from the lagoon within a barrier reef, was surely there while the reef was forming around it; and the features of the island shoreline will, as Darwin long ago pointed out for still-standing islands and as Dana a few years

later pointed out for subsiding islands, afford critical evidence regarding the changes which the island suffered contemporaneously with the formation of the encircling reef. These considerations may make it clear why my work has been almost wholly confined to the central islands of barrier reefs, though several examples of uplifted reefs were not neglected.

*Coral Reefs around Still-standing Islands.* The various theories of coral reefs may be divided into two groups. Those of the first group, some six or seven in number, postulate a fixed relation between land and sea level during the development of the reefs; these will be called the still-stand theories. The two theories of the second group postulate a change in the relative level of land and sea during the development of the reefs. As far as the barrier reefs that I have visited are concerned all the theories of the first group must be rejected, because within every one of these barrier reefs the embayments or drowned valleys, C, C, C, figure 1, by which the shoreline of the central volcanic island is indented, give through Dana's principle of shoreline development indisputable evidence of recent submergence. I believe that the same conclusion applies to all barrier reefs, first for the reason that those which I visited were not selected because they were thought to be in any way unlike other members of their kind, but because they were easily accessible; and second because all the charts of other barrier reefs that I have examined show that their central islands also have embayed shorelines. For none of these islands can any one of the still-stand theories hold good.

*Coral Reefs and the Glacial Period.* It remains to inquire which one of the two theories that postulate a change in the relative level of land and sea best accounts for the facts of barrier reefs and their associated central islands. One of these is Darwin's simple theory of a slowly subsiding ocean bottom, as a result of which the islands gradually sink, diminish in size, and eventually disappear, while their fringing reefs grow upwards and are converted into barrier reefs and atolls. The other is the more complicated "glacial control theory" lately elaborated by Daly with especial reference to atolls. It begins by assuming still-standing foundations, above and around which out-growing reefs of less or greater size, with shallow lagoons or none, were developed in preglacial times; a lowering of sea level is then inferred during the glacial period, when a significant amount of sea-water was withdrawn to form the continental ice sheets, and when in consequence of lowered ocean temperature the corals of most reefs were killed; next follows an abrasion of the unprotected preglacial reefs so as to

reduce them to flat platforms a little below the lowered sea level; and finally, when a rising temperature melts the continental ice-sheets and the sea surface is raised and warmed, and the corals are permitted to grow again, reefs are built up to the present sea level around the margin of the abraded platforms, producing barrier reefs or atolls as the case may be, around the lagoon that covers the abraded platform. The embayments of the central island within a barrier reef are explained as drowned valleys that were eroded while the sea level was lowered.

After careful consideration I have had to discard this theory, except insofar as it may have produced small results that are altogether subordinate to the larger effects of some more efficient cause. My reasons are in brief that, if the lagoons of large atolls have been abraded across their whole diameter of 20 or 30 miles, the central volcanic islands within narrow-lagoon barrier reefs should have been strongly cliffed by the lowered sea all around their shores, and their lagoon waters should now rise on the cliffed spur ends; but this is not the case; the spurs generally dip gently into the lagoon with small cliffs or none. Further, if the embayments of the central islands within barrier reefs occupy new-cut valleys that were eroded during the lowered sea-stand of the glacial period, the up-stream parts of such new valleys should be visible beyond their embayed parts, and should there appear as incisions beneath the floors of preglacial valleys, producing a valley-in-valley landscape; but in the hundreds of embayments that I saw, no such composite valleys occurred. Finally, it is doubtful if the lowering of sea temperature generally sufficed to kill the corals and expose the reef flanks unprotected from sea attack; for on the atolls of the Paumotu Agassiz found many instances of slightly uplifted reef limestones, which he regarded as 'Tertiary,' and hence as preglacial, on the inner border of the present encircling reefs; and in such cases the lagoon floors could not be the result of marine abrasion in glacial time.

*Submergence and Subsidence.* It might now appear as if no other cause than subsidence, as postulated in Darwin's theory and apparently confirmed by Dana's explanation of embayed shorelines, remained available; yet all the observable facts of the case may be fully as well explained by a rise of the sea surface, caused by an upheaval of the sea-bottom elsewhere, as by a sinking of the islands and of the sea-bottom on which they stand; but a deliberate discussion of this alternative shows it to be highly improbable because it demands extravagant crustal deformation and because it involves all the coasts of all the continents as well as the coral-reef islands. If it be set aside, only

Darwin's theory remains, the simple sufficiency of which stands forth all the more clearly in contrast with the failing inefficiency of its competitors.

*The Problem of Atolls.* The conversion of barrier reefs into atolls by a continuation of the process that has converted fringing reefs into barrier reefs is a highly probable matter; for it would be unreasonable to suppose that this process, whatever it is, should always have stopped before the central islands of barrier reefs were wholly submerged, and should never have worked in neighboring areas where reefs of identical form, but without a central island, are given another name. And as the converting process has, with so high a degree of probability, been shown to be subsidence of the ocean bottom in the region concerned, and not change of ocean level during the glacial period or uplift of the ocean bottom in some other region, it appears reasonable to explain atolls as well as barrier reefs by subsidence. This conclusion becomes all the more reasonable when the intimate association of barrier reefs and atolls in the Fiji and Society groups and elsewhere is noted. Nevertheless the problem of atolls cannot be now regarded as absolutely solved, nor can it be absolutely solved until we make addition to our knowledge now undreamed of.

*Reefs and Reef-Platforms.* A modification of Darwin's theory has lately been proposed by Vaughan, who regards recent submergence, proved by the embayments of the central islands, as the determining cause for the up-growth of existing barrier reefs, but who interprets the deeper and larger part of the entire reef-mass as an independent "platform" of earlier origin. As this investigator has not yet published his views regarding the origin of the reef-platforms, his modification of Darwin's theory will not be here discussed farther than to note that it seems inapplicable to many barrier reefs in the Fiji and Society groups; that the discontinuity of certain barrier reefs seems to be explicable on the assumption of imperfect up-growth during and after a recent and rapid subsidence, as well as on the assumption of independent origins for the reefs and their platforms; and that, while the extension of reef-platforms outside of the coral zone, as in the case of the Great Barrier reef of Australia, truly suggests a dual origin of reef-masses, this does not exclude the contemporaneous growth of platform and reef within the coral zone during long-continued but irregular or intermittent subsidence.

*Summary of Results.* The general result of my voyage, already announced above, as well as several special results, may here be concisely stated:

Darwin's original theory of subsidence gives by far the most satisfactory explanation of all the barrier reefs that I have visited in the Pacific or studied on large-scale charts; and as atolls often occur in association with barrier reefs, the theory of subsidence appears to give the best explanation of such atolls also. Atolls that are not associated with barrier reefs may be of some other origin, but this does not seem probable.

The elevated reef along the south coast of Oahu, Hawaii, was formed during or after a sub-recent period of subsidence, for its limestones enter well-defined valleys of erosion.

The Fiji group has suffered various movements of subsidence and uplift by which its many islands were affected in unlike ways. Uplift has taken place at different times, for some of the elevated reefs are elaborately dissected, others are very little dissected, and still others remain at sea level. The uplifted reefs seem to rest unconformably on subaerially eroded volcanic centers, hence the centers must have been above sea level to suffer erosion; they must have been depressed to receive the unconformable reef deposits; and the compound mass must then have been elevated to lay bare the reef. In one island (Vanua Mbalavu) the uplifted reef has been maturely dissected and partly submerged, as indicated by its embayed border, and a new barrier reef has grown up outside of it. Thus all the Fiji reefs, those now elevated as well as those at sea level, appear to have been formed during periods of subsidence.

The extensive barrier reef of New Caledonia has grown up during a recent subsidence by which that long and maturely dissected island has been much reduced in size and elaborately embayed; but unlike most encircled islands this one was strongly cliffed around its southeastern end and along much of its northeastern side before the recent subsidence took place.

The two southeastern members, Maré and Lifu, of the Loyalty group, are former atolls, evenly uplifted 200 or 300 feet; Maré has a small knob of volcanic rock in its centre. Uvea, the northwestern of the three Loyalty islands, is a slightly tilted atoll.

The New Hebrides show signs of uplifts in their elevated reefs, and of depressions in their embayments. There is some evidence that certain uplifted fringing reefs on the island of Efate, near the center of the group, were formed during pauses in a subsidence that preceded their uplift, and not during pauses in their uplift as inferred by Mawson. Espiritu Santo, in the northwest, has several large embayments inter-

rupting its fringing reefs; this is taken to mean that earlier fringing reefs were drowned by rapid submergence, so that they did not grow up in off-shore barrier reefs.

The Great Barrier reef of Australia, the largest reef in the world, with a length of some 1200 miles and a lagoon from 15 to 70 or more miles wide, has grown upward during the recent subsidence by which the Queensland coast has been elaborately embayed, as was pointed out by Andrews in 1902.

Five islands of the Society group exhibit unequivocal signs of recent submergence in their intricately embayed shore lines, as has lately been shown by Marshall; the cliff-rimmed island of Tahiti, the largest and youngest of the group, has suffered moderate submergence after its cliffs were cut, but its bays are now nearly all filled with delta plains; hence a pause or still-stand has followed its latest submergence. All the barrier reefs of this group appear to have been formed during the recent submergence, due to regional subsidence, that embayed their central islands.

## A METHOD OF PROPHESYING THE LIFE DURATION OF SEEDS

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Seeds that will withstand drying in the air without injury retain their viability under herbarium conditions from one to one hundred and fifty years. Seeds that will not withstand drying in the air generally have a longevity of only a few months. Ewart<sup>1</sup> has suggested that seeds retaining their viability for three years or less be called microbiotic; for three to fifteen years, mesobiotic; and for more than fifteen years, macrobiotic. The cause of the loss of viability with storage has been a subject of considerable study. Two explanations have been offered: exhaustion of stored foods and degeneration of digestive and oxidizing enzymes. Both of these explanations have proved incorrect for both foods and enzymes are present in almost full force for some years after viability is lost. Certain facts have led us to surmise that the gradual loss of viability with storage is due to a slow coagulation of the proteins in the plasma of the embryo. The fall of longevity with rise of temperature and of moisture content of the seed indicate this.

Certain known facts concerning proteins make the experimental investigation of this hypothesis possible. Chick and Martin<sup>2</sup> have